Optimum Sampling Strategy for Sediment-Associated Pesticides in Suisun Bay

Bryan Jennings, David Schoellhamer, and Kathy Kuivila (USGS)

In an estuary, concentrations of many constituents, such as salt and suspended solids, can vary at several time scales. The diurnal and semidiurnal tidal cycles can account for much of the variation. At longer time scales, variations can be caused by freshwater inflow, seasonal winds, and the spring/neap cycle. If the longer time scales are of primary interest, numerical filters (Stearns and David 1988) can be applied to tidal time series of concentrations to remove tidal variations and to produce a tidally averaged (or residual) time series. For example, residual time series have been analyzed to evaluate effects of seasonal winds and the spring/neap cycle on suspended solids concentration in South San Francisco Bay (Schoellhamer 1996) and effects of barometric pressure, wind, and the spring/neap cycle on suspended solids flux at Mallard Island (Tobin and others 1995), South San Francisco Bay (Lacy and others 1996), and Spoonbill Creek (Warner and others 1997).

Understanding the temporal variability of suspended solids concentration in Suisun Bay is necessary for accurate collection and interpretation of chemical and biological data. High runoff during winter produces the greatest concentrations of suspended sediments and dissolved pesticides in the lower Sacramento River (Kuivila and Foe 1995; MacCoy and others 1995). The greatest concentrations of sediment-associated pesticides are likely to occur at this time also. These pesticides may adversely affect the ecosystems of San Francisco Bay.

A sampling strategy must account for major variations, but collecting and processing water samples for sediment-associated pesticide analysis are time-consuming and expensive. Logistically, it is feasible to sample and analyze a maximum of two samples per day for sediment-associated pesticides for a 2-to 4-week period of high runoff. Such limitations on sampling and analysis are a common problem affecting estuarine sampling programs. This constraint is an important consideration in developing an effective sampling strategy for studies of residual trends of sediment-associated pesticides at Mallard Island (Figure 1).

In contrast to twice-a-day sediment-associated pesticide sampling, suspended solids concentration time-series data are collected every 15 minutes at Mallard Island, for a total of 35,040 data values per year (Buchanan and Schoellhamer 1996). The suspended solids concentration time series is collected using an OBS (optical backscatter) sensor positioned 1 meter below the water surface.

Water samples are collected and analyzed for suspended solids concentration, and these analyses are used to calibrate the sensor outputs to suspended solids concentration, measured in milligrams per liter.

The purpose of this study was to develop a twice-a-day sampling strategy for suspended solids concentration at Mallard Island that best reproduces the residual (tidally averaged) near-surface suspended solids concentration computed using the entire time series (96 sampling times per day) for high delta discharge conditions and to use this strategy for sampling sediment-associated pesticides. Assuming that the concentration of sediment-associated pesticides varies in a similar manner to suspended solids concentration, the optimum sampling strategy for suspended solids concentration would also be the optimum sampling strategy for sediment-associated pesticides.
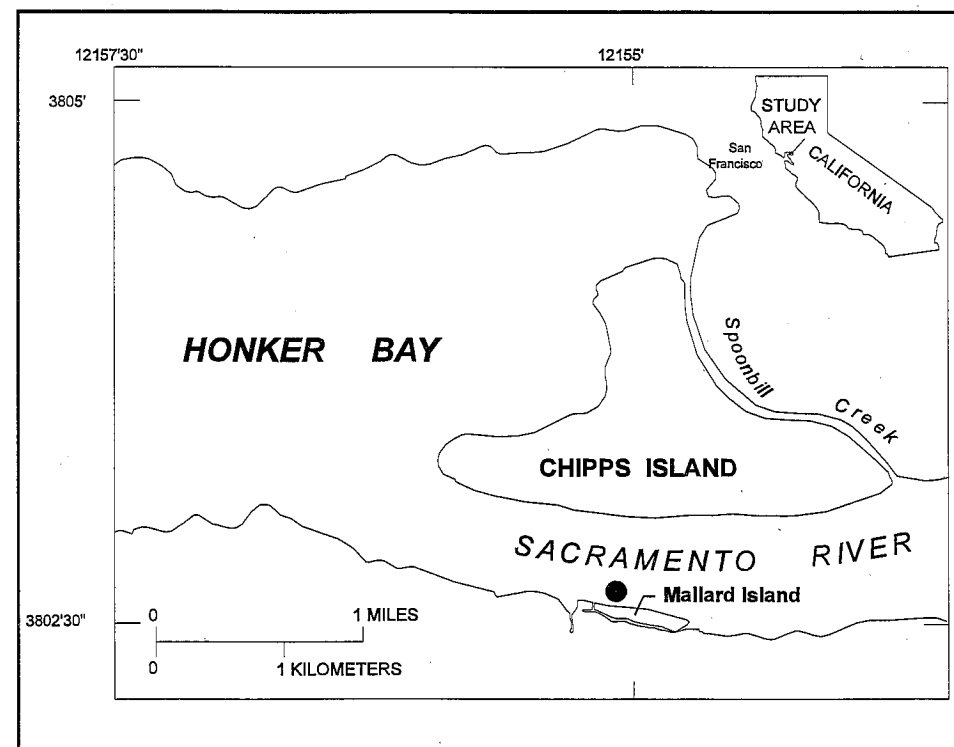

Figure 1
STUDY AREA

Methods

The method used to determine the optimum sampling strategy for suspended solids concentration is summarized in Figure 2. The near-surface suspended solids concentration time series (15-minute data) measured at Mallard Island and a corresponding predicted current (velocity) time series are used to optimize sampling strategy. The residual suspended solids concentration time series is determined by passing the raw suspended solids concentration time series through a low-pass Butterworth numerical filter to remove tidal influence on suspended solids concentration at Mallard Island. The predicted current time series is determined by applying tidal harmonic analysis to previously measured current time series at Mallard Island (Cheng and Gartner 1984). Predicted times of ebb and flood tide can be obtained using the resulting predicted current time series. High runoff is assumed to have no effect on the predicted tidal cycle, which is a potential source of error.

Using these tidal predictions, the 15-minute suspended solids concentration data are subsampled twice a day
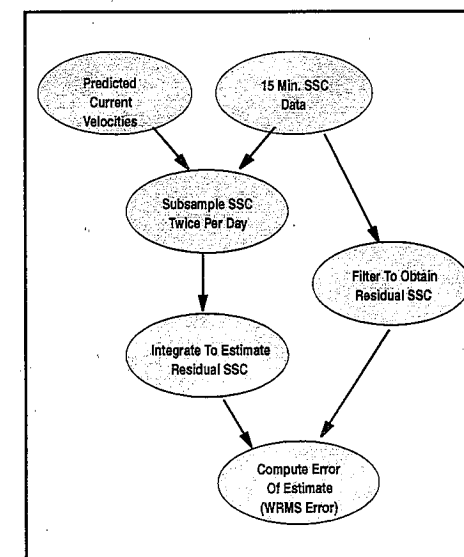

Figure 2
PROCEDURE USED TO EVALUATE
SUSPENDED SOLIDS CONCENTRATION
SAMPLING STRATEGIES

at selected times of ebb and flood tides. An estimated residual suspended solids concentration time series is determined from the subsampled suspended solids concentration with the mean-value theorem of calculus using a four-point trapezoidal integration over a 2-day period. This integration is numerically equivalent to computing a time-weighted mean suspended solids concentration for every four consecutive data points. Integrating the suspended solids concentration subsamples removes tidal influence and allows for direct comparison to the residual suspended solids concentration time series. A suspended solids concentration-weighted root mean square error is calculated to compare the integrated suspended solids concentration subsample to the residual suspended solids concentration time series.

Evaluation Results of Sampling Schemes

Suspended solids concentration time series data collected 1 meter below the water surface at Mallard Island during the winter high runoff periods of water years 1995 and 1996 (Figures 3 and 4) (Buchanan and Schoellhamer 1996) were used to optimize the sampling scheme. Mean suspended solids concentration for these data is 58 mg/L. Daily mean delta discharge associated with each time period also is shown in the figures (DWR 1986). The highest peak of suspended solids concentration occurred as delta discharge began to increase. Peaks in delta discharge that occurred after the initial increase produced smaller peaks in suspended solids concentration, similar to observations by Goodwin and Denton (1991). Breaks in the suspended solids concentration time series were caused by periodic power outages at the sampling station and by fouling

of the OBS sensors. Suspended solids concentration data for these periods provided six continuous data segments for analysis.
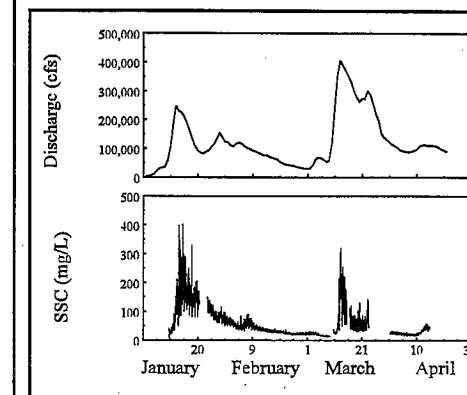

Figure 3
DAILY MEAN DISCHARGE AND
SUSPENDED SOLIDS CONCENTRATIONS
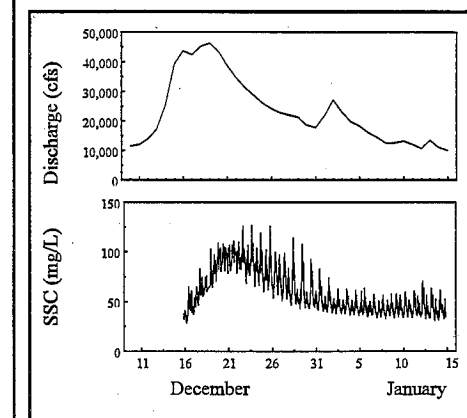AT MALLARD, WATER YEAR 1995

Figure 4
DAILY MEAN DISCHARGE AND
SUSPENDED SOLIDS CONCENTRATIONS
AT MALLARD, WATER YEAR 1996

Discharge from the delta and the resulting pattern of the suspended solids concentration time series at Mallard Island were very different for water years 1995 and 1996. In 1995, discharge from the delta was high, causing sediment to be advected past Mallard Island. Essentially, Suisun Bay was more like a river than an estuary, and there was little deposition or resuspension of sediment near Mallard Island. Semidiurnal tidal transport of suspended solids concentration at Mallard Island resulted in two daily suspended solids

concentration peaks. In contrast, the maximum discharge in 1996 was less than that of 1995. Suspended solids concentration at Mallard Island was controlled by local deposition during slack tide and resuspension during maximum tide during these discharge conditions — resulting in up to four daily suspended solids concentration peaks. Uncles and Stephens (1993) made similar observations in the Tamar Estuary, UK. Because of the wide range in conditions, these 2 years provide good data sets for determining an optimal suspended solids concentration sampling strategy that is applicable to a variety of large delta discharges.

The optimization of a sampling strategy for suspended solids concentration is dependent on two variables: the time the samples are collected relative to the tidal cycle and the numerical integration scheme used to determine residual values. Figure 5 is an example of the process used to examine the suitability of a specific sampling strategy for water year 1995. The solid line in Figure 5A is the raw suspended solids concentration time-series data collected by an OBS sensor every 15 minutes. Each star represents a subsample of the raw suspended solids concentration time series, in this case, the slack tide preceding and following the ebb tide occurring nearest noon daily. The selected times used for the twice-a-day subsamples are determined using the predicted current time series. The solid line in Figure 5B is the residual suspended solids concentration time series, and the diamonds are the four-point trapezoidal integration of the subsampled suspended solids concentration data.

A WRMS error is calculated as the weighted root-mean-square difference between the residual suspended solids concentration time series and the integrated suspended solids con-
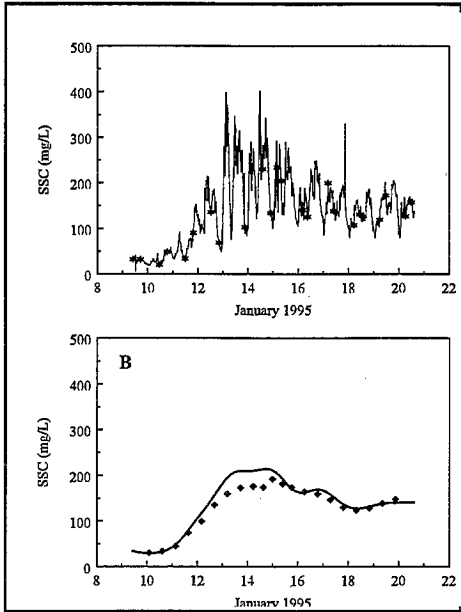

Figure 5
OPTIMUM SAMPLING STRATEGY DURING THE FIRST FLUSH AT MALLARD ISLAND, WATER YEAR 1995

centration subsamples. This same process is used to examine and compare all sampling strategies for the water year 1995 and 1996 high runoff data (Figures 3 and 4). A two-point integration — taking the mean of twice per day samples — was examined, but did not reproduce the residual suspended solids concentration as well as the four-point trapezoidal integration.

Subsampling strategies are compared to the residual suspended solids con-

centration time series using WRMS error (Table 1). The WRMS error was used because we are most interested in estimating residual suspended solids concentration at its peak. Simply using root mean square error would give equal weight to all suspended solids concentration subsample data. At relatively low discharge conditions, there is little variation in the suspended solids concentration time series. Hence, all sampling strategies perform comparably well, which is reflected in the root mean square error. Using the WRMS error separates the sampling strategies by their capability to reproduce accurately the residual suspended solids concentration time series at the suspended solids concentration peak.

Sampling once (12 noon) daily or twice daily at a 12-hour interval (10 am and 10 pm) has a large WRMS error and either is an unsatisfactory sampling strategy. These results demonstrate the importance of considering the tidal cycle at Mallard Island and other tidally affected locations when sampling for suspended solids concentration or other related constituents. Although this example pertains to large discharges, we expect that the tidal cycle usually will affect

the concentration of constituents in the water column at a fixed point in San Francisco Bay and that tidal variation must be considered to determine accurate residual values.

There are several nearly equivalent sampling strategies based on WRMS error (Table 1). Sampling at slack after ebb tides and sampling higher ebb and higher flood tides result in relatively high WRMS error. The WRMS errors of the remaining sampling strategies are lower, nearly equivalent, and equal to about 20 percent of the mean suspended solids concentration. The WRMS error, however, is not the only factor that needs to be considered when selecting a sampling strategy. Safety issues and the likelihood that a sample would not be collected also must be considered. Fog at this time of year (winter) can cause difficulty in getting to the sampling site; one missed sample causes a break in the residual time series of about 60 hours. Sampling is safer during daylight hours, and having 6 hours or less between the two daily samples assists with field logistics.

Considering all factors, the optimum sampling strategy selected for suspended solids concentration at Mallard Island is sampling the slack tide preceding and following the ebb tide that occurs nearest noon daily. Results of this sampling strategy are shown in Figure 5 (WY 1995) and Figure 6 (WY 1996). Sampling at these times and using a four-point integration proved to be an effective sampling strategy for a variety of peak delta discharges. By sampling around the ebb tide that occurs nearest noon, the possibility of missing a sample due to fog has been minimized, and at least one sample each day is taken during daylight hours. In addition, time between two daily samples is about 6 hours, making logistics and travel more efficient.
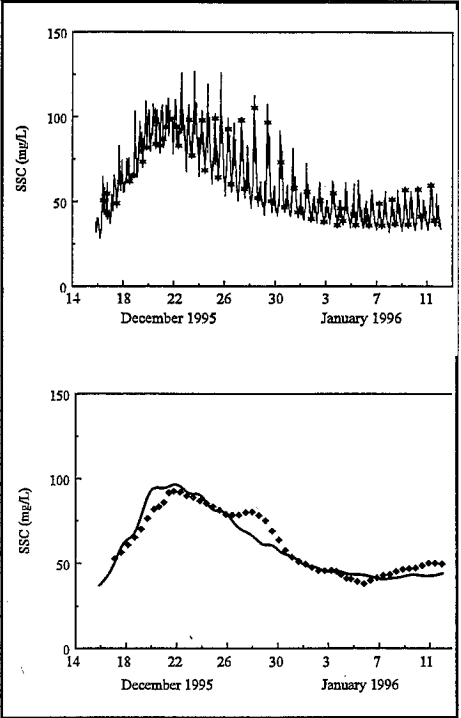

Figure 6
OPTIMUM SAMPLING STRATEGY DURING THE FIRST FLUSH AT MALLARD ISLAND, WATER YEAR 1996

Conclusions and Future Work

The conclusions of this study are:

- Sampling at fixed time intervals is not satisfactory; the tidal cycle must be taken into consideration;
- Data collected during peak discharge indicate that sampling the slack tide preceding and following the ebb tide nearest noon is among the best methods; and
- Using this sampling strategy improves safety, makes logistics and travel more efficient, and minimizes the possibility of a missed sample.

For this study, suspended solids concentration can be considered an indicator of riverine waters entering Suisun Bay. Thus, this methodology should be applicable to any constituent associated with a source associated with suspended solids in the Central Valley during periods of high runoff.

Suspended solids concentration and sediment-associated pesticides at

Mallard Island were sampled during the winter of water year 1997 as delta discharge began to increase in January. This was the first period of high runoff of the water year and was expected to carry the highest peak of suspended solids concentration and presumably the highest peak of sediment-associated pesticide concentrations. Samples were collected at slack water preceding and following the ebb tide that occurred nearest to noon daily. The analytical results will not only verify the effectiveness of the sampling strategy for suspended solids concentration, but will also verify the assumption that the concentration of sediment-associated pesticides varies in a similar manner to suspended solids concentration.

References

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Table 1
WEIGHTED ROOT MEAN SQUARE ERROR FOR
SUSPENDED SOLIDS CONCENTRATION SAMPLING STRATEGIES AT
MALLARD ISLAND, WATER YEARS 1995 AND 1996

Sampling Strategy	WRMS Error (mg/L)
Sampling at 12 Noon Daily*	26.1
10 am and 10 pm Daily	18.0
Slacks After Ebb Tide	20.6
Slacks After Flood Tide	11.5
Higher Max Ebb and Higher Max Flood Tide	16.3
Slack After Higher Ebb and Flood Tide	12.6
Slack After Lower Ebb and Flood Tide	11.8
Slack Preceding and Following Higher Ebb Tide	12.3
Slack Preceding and Following Lower Ebb Tide	11.1
Slack Preceding and Following Ebb Tide Occurring Nearest Noon	12.0

*Subsampled once per day with no integration.

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Delta Outflow
Chris Enright, DWR

Between July 1 and September 30, the average Delta Outflow Index was 7,432 cfs. The largest outflow was on August 11, at 13,758 cfs, and the smallest was on September 26, at 2,096 cfs. Combined SWP/CVP pumping averaged about 9,750 cfs during this period. SWP pumping was severely curtailed from August 9 through August 15 due to emergency work to repair aqueduct lining in pools 10 and 12. The SWP pumped at a rate of 900 cfs per day for the CVP wildlife refuge from July 23 through August 3. The SWP also pumped CVP Cross Valley water at 1,260 cfs per day from August 4 through August 8. The SWP started pumping 1997 CVP spring actions makeup water on September 17, at a rate of 1,500 cfs during on-peak hours and continued at this rate through October 9.

Delta Outflow Index
July-September, 1997

Pumping from the Delta
July-September 1997
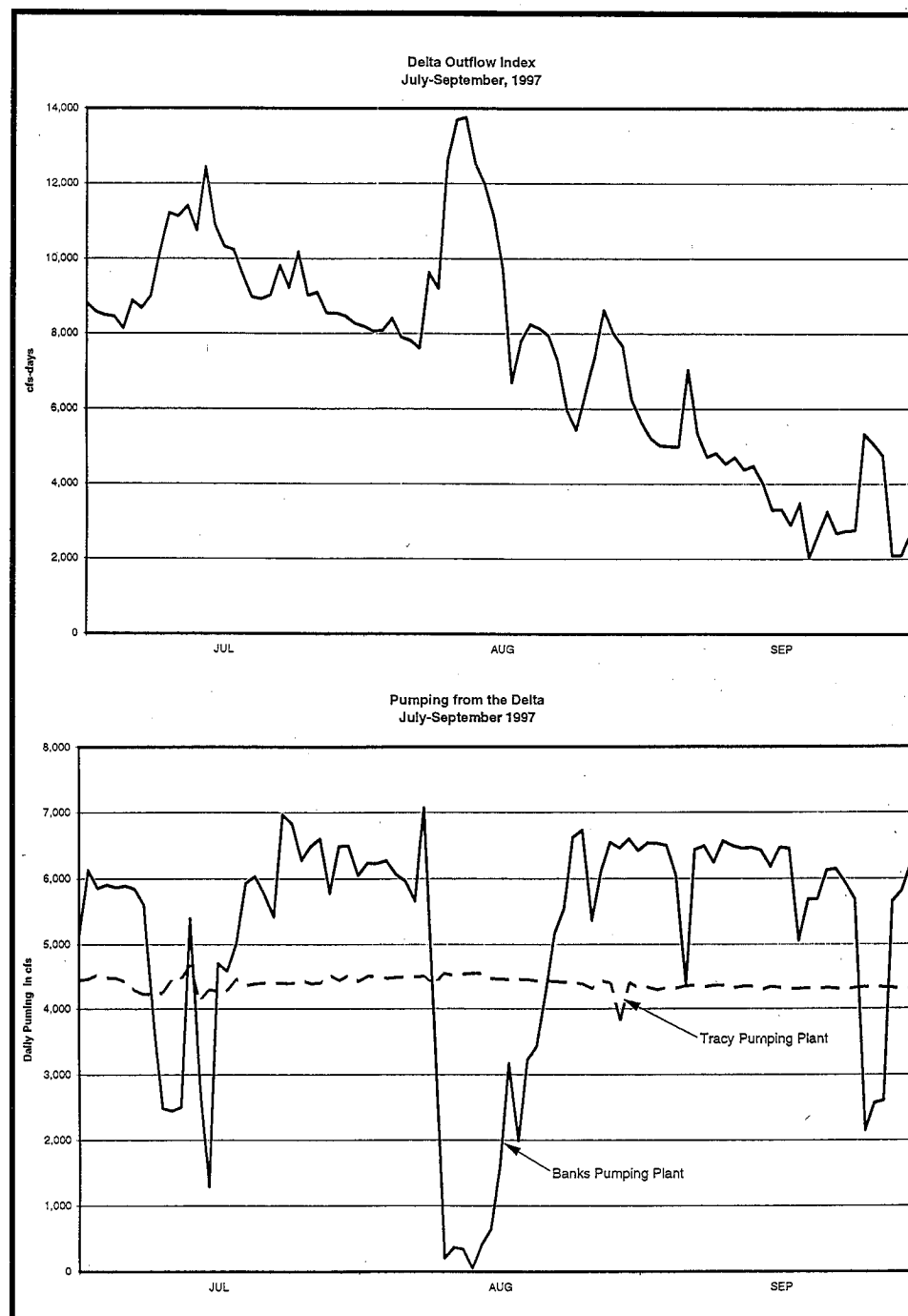
First Annual IEP Monitoring Survey of the Chinese Mitten Crab in the Delta and Suisun Marsh
Tanya Veldhuizen, DFG

The Chinese mitten crab, *Eriocheir sinensis*, native to coastal rivers and estuaries of China and Korea along the Yellow Sea (Panning 1938), was first discovered in South San Francisco Bay in 1992 and quickly spread throughout the estuary during the next several years. Mitten crabs were first collected in San Pablo Bay in the fall of 1994, in Suisun Marsh in February 1996, and in the Sacramento-San Joaquin Delta in August 1996 (Hieb 1997). The current known distribution of the Chinese mitten crab in the delta extends north up the Sacramento River to the Port of Sacramento, east to Stockton (Fourteen-mile Slough), and south to Fabian and Bell Canal. The crab is also distributed throughout Suisun Marsh. We expect the known distribution to expand this fall as emigrating adult crabs continue to be incidentally caught by fishermen.

This summer was a pilot year for implementing an annual monitoring program for juvenile mitten crabs. The 45 adult crabs collected last fall and winter indicated the population in the northern estuary was large enough to be detected by monitoring. Because the juvenile crab's diet is comprised mainly of vegetation, capturing them with baited traps was not feasible. Instead, juvenile crabs were excavated from the burrows they dig for protection from predators and desiccation during low tide (Panning 1938).

After surveying the delta and Suisun Marsh for potential sites in late June and early July, 15 monitoring stations were selected based on several criteria: sites had to be tidally influenced, contain adequate expanses of unrocked bank exposed during low tide, and be accessible by vehicle. We attempted to select stations to achieve an even distribution throughout the delta and marsh, but due to large expanses of riprapped bank or inaccessibility, portions of the delta may be under-represented.

We are monitoring 4 marsh stations and 11 delta stations. In the delta, 8 are core stations and 3 are peripheral stations. Core stations are sampled twice a year separated by 4 weeks. Peripheral stations are sampled once a year, and represent the upstream limit of where juvenile mitten crabs can be expected to burrow.

Each station was surveyed during low tide when the bank was exposed. We searched for mitten crabs along a 5-meter transect paralleling the bank and extending from the water line to the high tide line or to the top of the bank. The transect height was measured at 1-meter intervals, and the average height was used to determine the total area of the transect. For core stations, the second transect was placed within 0.25 mile of the first transect, preferably adjacent to the original. Transect searches involved excavating all cavities, such as burrows and rotted root tunnels, and examining all debris, driftwood, rootwads, and ponded water for mitten crabs.

We measured carapace length and width at the widest point of each crab. Crabs larger than 9 millimeters were sexed, and all were returned to the same location where captured. We also recorded vegetation and soil types, bank profile, water salinity and temperature, and tidal phase.

Sampling began in late July and continued through early September. Average density was highest at the Suisun Marsh stations (Figure 1) — Denverton Slough had the highest (3.07 crabs/m²) and Montezuma Slough had the lowest (0.55 crabs/m²). During the second survey, density increased at the Montezuma and Denverton Slough stations and decreased at the Suisun and Hill Slough stations. Mean carapace width was 15.3 millimeters for both surveys (n = 25, survey 1; n = 36, survey 2). Salinity was 4.4-7.2 l and was highest at Denverton Slough on both surveys.

Crabs were found at only 4 of the 8 core stations in the delta (Figure 1). Average density was relatively low, ranging from 0.31 crabs/m² in Middle River near the railroad tracks on Jones Tract to 0.13 crabs/m² in Fabian and Bell Canal at Tracy Oasis Marina. Mean size was also 15.3 mm carapace width (n = 11); all crabs were collected from fresh water. Density at all 4 of these core stations declined to zero on the second survey. No crabs were found at the peripheral stations.

Juvenile crab density in the delta and Suisun Marsh is significantly less than in South San Francisco Bay sloughs. Average density for 1997 in South Bay sloughs was 3.38 to 6.31 crabs/m² in July and 5.02 to 15.87 crabs/m² in August (Diana Theriault, UC-Berkeley, personal communication). Previously, a maximum density of 30 crabs/m² was reported (Halat 1997).

Both the SWP and CVP pumping plants collected the first juvenile mitten crabs this summer. Skinner Fish Facility caught one crab of 29 mm carapace width in August. Tracy Fish Facility captured juvenile crabs in the holding tanks beginning in late June. Mean size of age-0 juveniles was 15.0 mm carapace width in June (n = 1), 17.6 mm in July (n = 21), 23.2 mm in